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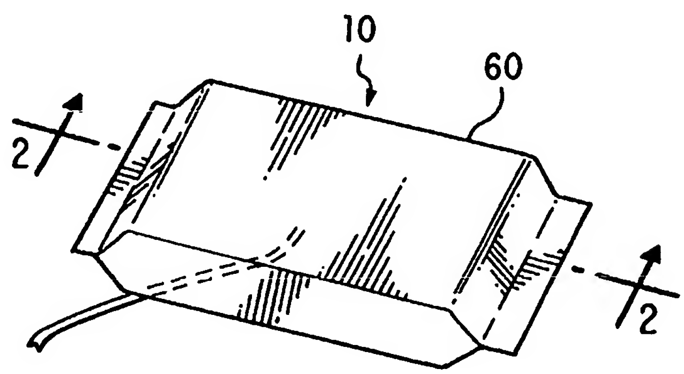
(54) Title: VERY THIN INFLATOR AND METHOD OF MAKING AND USING SAME

(57) Abstract



A compact, i.e., very thin inflator device and a gas-generating composition therefor. The gas-generating composition comprises an azido polymer, a curing agent and an oxidizer. These three components preferably are combined in proportions sufficient to generate, upon combustion at a pressure between about atmospheric and 1000 psi greater than atmospheric and, preferably, about 250 psi above atmospheric pressure, at least about 900 liters per second of a substantially non-noxious and non-toxic combustion product. The gas-generating composition, optionally mounted upon a substrate, may be contacted with a layer of an ignition-enhancing material adapted to transmit heat to the gas-generating composition and, thus, facilitate the combustion thereof.

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VERY THIN INFLATOR AND METHOD OF MAKING AND USING SAME

FIELD OF THE INVENTION

The invention relates to a compact, *i.e.*, very thin inflator device and gas-generating composition therefor suitable for rapidly inflating a flexible bag or filling a container to an elevated pressure. One preferred application of the present invention is for use in motor vehicle passive restraints in which a flexible and collapsible bag is inflated rapidly upon sudden deceleration of the vehicle by operation of the inflator device in order to protect the vehicle occupants from injury.

BACKGROUND OF THE INVENTION

Inflators capable of rapid gas-generation have found widespread use in many fields. One such application involves motor vehicle passive restraint systems which reduce the large number of deaths and injuries occurring annually in automobile accidents. Air bags and inflatable belts for use in such passive restraint systems are typically operatively associated with inflator devices which are generally activated by an inertial switch or sensor capable of detecting rapid deceleration of a vehicle, such as that which occurs upon impact between an automobile and another object. When the inertial switch is triggered, it causes the associated inflator to quickly inflate a collapsed flexible structure which is deployed into a protective position in front of the occupant. The bag or belt must inflate extremely rapidly after the primary impact in order to protect the vehicle occupants from injury. In order to meet such a requirement, the bag should be fully inflated within about 15-65 milliseconds after inflation has been initiated.

A variety of conflicting design considerations must be taken into account in developing an effective air bag

passive restraint system. First, the inflator must be capable of producing and releasing a sufficient quantity of gas to the air bag within the time limitation required of such a system. Given the time requirements involved in air bag restraint systems, inflators typically must be capable of filling an air bag in an environment wherein the pressure is approximately atmospheric pressure, *i.e.*, 14.7 psi, with gas at a rate of at least about 900 liters per second and in a range of about 900-3000 liters per second. Automobile manufacturers specify that inflaters produce pressurization rates between about 5 and about 24 kPa per msec. when deployed at 21° +/- 3° C to fill an inflatable bag which is in a nearly atmospheric pressure environment.

Other considerations in designing an inflator for a passive airbag restraint system, particularly for automotive applications, involve the toxicity and noxiousness of the gas which fills the air bag. That is, the inflator for an automotive air bag must generate or release gas which meets or surpasses certain non-toxicity requirements in order to protect the occupants in case the air bag ruptures, particularly since some air bags are designed to deflate by releasing the gas used to inflate them within the confines of the interior of the vehicle. Otherwise the gas may injure or cause illness to the occupants. For example, the release of too much carbon monoxide could cause injury and even be deadly to the occupants of the vehicle. Toxicity requirements are controlled by certain well-known specifications required by the automotive manufacturers which are set in accordance with health requirements. One reference that is helpful in defining those requirements is the Occupational Safety and Health Administration ("OSHA") workplace breathing air standards.

In addition, the gas released into the air bag must meet certain energy transfer restrictions so that it will not

burn or deteriorate the integrity of the bag. Insuring that the energy transferred during the inflation event does not burn or deteriorate the bag protects the occupants from burns and other injuries.

Packaging restrictions add a further design consideration in the development of air bag inflators. For example, weight and size are primary factors in determining the suitability of vehicle inflator/module designs. Weight reduction translates into fuel economy improvements and size reduction, *i.e.*, compactness, permits greater styling flexibility. For styling reasons and to facilitate customer-acceptance, and so as not to interfere with the occupants' movement, comfort or the driver's line of vision, it is desirable to arrange the inflator so as not to be obtrusive, and yet have it positioned so that it effectively accomplishes its intended task. In order to meet these styling and customer-acceptance parameters, the inflator must be capable of being packaged in a variety of different shapes and in a compact manner. The emphasis on weight reduction for the purpose of fuel conservation in motorized vehicles, and the recent developments in passenger air bags, rear-seat occupant air bags, side-impact air bags, inflatable seat belts and seat belt air bags and knee bolster air bags as well as the contemplated use and development of air bags adapted for installation in the A and B pillars of vehicles and other small bags of 1 to 30 liters of volume, have created the need and demand for a light and compact passive restraint inflation system.

There are two basic techniques which are typically employed in the prior art to supply the gas in air bag restraint systems. In the first such technique, the inflating gas is provided as a compressed gas stored onboard the vehicle within a pressure vessel, for example as shown in U.S. Patent No. 3,411,808 to Chute and U.S. Patent

No. 3,413,013 to Wissing *et al.* In the other technique, described, for example, in U.S. Patent Nos. 3,880,447 to Thorn *et al.*, 4,068,862 to Ishi et al., 4,711,466 to Breed, and 4,547,342, 4,561,675, and 4,722,551 to Adams *et al.*, the bag is inflated by igniting a pyrotechnic gas-generating propellant composition and directing the resultant gaseous combustion products into the bag.

These two techniques are relied upon to produce three categories of inflators with the first category relying solely upon a pressurized reservoir of gas while the second category relies solely upon burning a combustible propellant to generate all of the gas necessary to fill the air bag. The third category, the so-called "hybrid" inflator, relies upon a combination of the stored gas and pyrotechnic methods described above to inflate the air bag.

The first category requires a reservoir of gas stored on board the vehicle at a very high pressure which is discharged into the bag immediately upon sensing the impact. In order to inflate the vehicle occupant restraint bag in an approximately atmospheric pressure environment in the required time of 0.015 to 0.100 seconds, that is to attain a fill volume rate of at least about 900 liters per second and more preferably approximately 3,000 liters per second, a relatively large reservoir of gas at pressures of 3,000 pounds per square inch ("psi") is stored in a pressure vessel. To open the pressure vessel in the very short time interval required to inflate the air bag, explosive actuated arrangements are employed, *e.g.*, for bursting a diaphragm or cutting through a structural portion of the reservoir.

This stored high-pressure reservoir technique has several shortcomings. First, the casing or housing used to store the compressed gas, referred to as the pressure vessel, must be constructed of heavy gauge steel or aluminum in order to withstand the elevated pressure and be relatively large

and bulky in order to contain a sufficient volume of gas. Second, the explosive actuated arrangements used to burst the pressure vessel add to the design complexity, cost and weight of the inflator. In addition, the gas within the reservoir has undesirable pressure history characteristics during air bag deployment since its pressure is highest as the bag commences its deployment and decreases as a function of time as the gas in the storage tank is depleted. The pressurized gas technique is also undesirable since a minor leak in the reservoir could result in all the gas escaping during the extended period that the air bag system may remain in the automobile prior to being deployed so that the system is unable to operate when needed.

Further, the adiabatic cooling of the pressurized gas as it expands from its storage condition of elevated pressure to the nearly ambient pressure of the inflatable bag reduces the effective volume of the gas available for inflating the bag. This cooling effect which is the result of inefficiency in filling the air bag requires the manufacturer to provide a total pressurized gas storage volume significantly greater than the gas required to fill the air bag if the gas within the bag remains at the initial ambient starting temperature of the gas in the pressure vessel.

In the second category of methods for inflating a passive restraint air bag, the gas generator contains an ignitable and rapid-burning pyrotechnic gas-generating propellant composition which burns to produce substantial volumes of hot gaseous products which are directed into the inflatable bag. Traditionally, these ignitable gas-generating propellant compositions have been in the form of powders or have been compression molded into a desired configuration, typically grains or solid particulates such as pellets, tablets or discs.

To inflate the bag within the required time parameters of 0.015 to 0.100 seconds, the ignitable propellant must be consumed or burned at a very rapid rate, *e.g.*, on the order of about 0.007 to 0.025 seconds. Current air bag technology requires that the gas-generating composition be burned at moderate to high pressure (between 1,000 and 15,000 psi above atmospheric pressure) in order to consume the gas-generating composition and produce the required volume of gas to inflate the bag within the prescribed time period. In other words, the gas-generating composition must be burned at 1,000 psi or more in order to consume enough of the propellant composition to produce the volume fill rate of at least 900 liters per second and, preferably, at least approximately 3,000 liters per second which is required to fill the air bag in an approximately atmospheric pressure environment in the required time. Burning the gas-generating composition at 1,000 psi and greater is necessary to attain the pressurization rates of between about 5 and about 24 kPa per msec. when deployed at 21° +/- 3° C required by the automobile manufacturers.

Pyrotechnic gas generators presently in use have several shortcomings, however. In order to attain their gas-generating requirements, such gas generators must withstand significant thermal and mechanical stresses during the gas-generating process. Specifically, the gas-generating propellant is ignited, combusts and burns at elevated temperatures and pressures which requires the casing (pressure vessel) surrounding the gas-generant to be capable of safely withstanding these elevated pressures at a specified safety factor. These strength requirements typically result in large, heavy and bulky inflators.

The third inflator category, *i.e.*, the hybrid inflator, utilizes a gas-generating propellant composition and a pressurized medium to meet the inflation requirements

for air bag restraint systems. As such, a hybrid inflator suffers many of the drawbacks of the other two categories of inflator designs, and is often of complex design. Such hybrid systems typically store pressurized gas at about 3,000 psi and in operation, they burn the gas-generating propellant grains to produce heated gas as well as to heat the stored gas. Typically, these hybrid systems have maximum expected operating pressures of 4,500-6,000 psi, although sometimes higher values are necessary.

European Patent Application No. 95200607.0 discloses a hybrid inflator which stores a pressurized medium of inert gas and oxygen, and which burns cylindrical gas-generating propellant grains. Initially, the static pressure within the inflator is about 4,000 psi. Within 1 millisecond after activation, the pressure in a first chamber where the gas-generating propellant grains are burned is about 10,000 psi while the pressure within the second chamber is about 7,000 psi and the pressurized medium is at about 4,500 psi.

The heater propellant in European Patent Application No. 95200607.0 burns at a combustion temperature ranging from about 2,000°k to 3,000°k at a rate ranging from 0.1 to 1.0 inches per second and an operating pressure of about 4,000 psi. The propellant used in the hybrid inflator disclosed by the reference is formed by combining a secondary explosive with a binder system. The secondary explosive is chosen from a nitramine propellant such as RDX (hexahydrotrinitrotriazine) or HMX (cyclotetramethylene tetranitramine), as well as PETN (pentacrythritol tetanitrate) and TAGN (triaminoguanidine nitrate). The binder system includes a binder and, optionally, a plasticizer and stabilizer. This hybrid propellant produces significant quantities of carbon monoxide and hydrogen, however, which are unacceptable for automotive inflation systems. To be useful for automotive inflation systems, a

pressurized medium which consists of an inert gas and oxygen mixes with the combustion gases of the hybrid propellant to form harmless carbon dioxide and water vapor.

The prior art inflator designs (*i.e.*, stored high pressure reservoir, pyrotechnic gas-generator and hybrid designs) require a pressure vessel or housing enclosure which must be adapted to withstand the pressure generated by the inflation event. Safe engineering practice requires that these enclosures be designed to contain at least 50-70% more than the highest pressure expected during use. The result of these design requirements, *i.e.*, containing a sufficient volume of gas at an elevated pressure or burning the gas-generating composition at moderate to high pressure (with a proper safety factor), is a large, heavy and bulky pressure vessel.

Practical passive restraint design also typically call for the pressure vessels used in air bag inflators to be toroidal or tubular in shape since these shapes are the most efficient at storing a pressurized gas. That is the largest volume and smallest amount of material is optimally stored in the form of a tube or toroid to hold a predetermined pressure. This limitation further restricts design flexibility by requiring either a toroidal or tubular configured installation space or increased weight and structural elements if the pressure vessel were to be altered from these shapes.

SUMMARY OF THE INVENTION

It is thus an object of the present invention to provide an inflator which is not subject to the historical weight, size and geometric constraints relating to its design and packaging, but which is instead simple, thin, *i.e.*, compact and light-weight. It is another object to eliminate the need for a pressure vessel in an inflator. It is yet a

further object to operatively associate a thin, compact light-weight inflator with an air cushion or flexible bag in a correspondingly thin package or module which inflator generates gas at a sufficient rate and within the toxicity requirements required in passive airbag restraint systems, and attains a maximum pressure below 1000 psi, more preferably below 250 psi and ideally below 5 psi above atmospheric pressure.

It is still another object of the invention to provide a novel gas-generating composition for use in such a thin, compact inflator which meets gas generation rate and non-toxicity requirements for passive air bag restraint systems at lower pressures than have been attainable heretofore. It is an additional object of the invention to provide a gas-generating composition which incorporates a low solids oxidizer system to minimize production of solids on combustion, thus reducing or eliminating the need for gas filtration, and an energetic binder capable of supporting atmospheric or near atmospheric pressure combustion. It is a further object of the invention to provide a gas-generating composition which can generate at least about 900 liters per second and preferably at least about 3,000 liters per second or more of non-toxic and non-noxious gas while burning at maximum pressure of below 1000 psi, more preferably below 250 psi and ideally below 5 psi above atmospheric pressure, *i.e.*, nearly atmospheric pressure.

It is another object of the invention to obtain high consumption and burning rates for a gas-generating propellant composition which burns at a relatively low pressure of below 1000 psi, more preferably below approximately 250 psi above atmospheric pressure and ideally down to nearly atmospheric pressure. It is still another object of the invention to provide a pyrotechnic inflator which produces non-noxious and non-toxic gas at

pressurization rates of between about 5 and about 24 kPa per msec. when deployed at 21° +/- 3° C when the gas-generating composition is burned at pressures below 1000 psi, more preferably below 250 psi, above atmospheric pressure and ideally down to nearly atmospheric pressures.

These and other objects are achieved by the use of a thin, compact inflator device including a correspondingly thin layer of a gas-generating composition comprising an azido-polymer, a curative (curing agent) and an oxidizer. The amount and type of oxidizer may be adjusted in a known manner to tailor the performance of the gas-generating composition. The gas-generating composition may also contain modifiers added to adjust the performance of the gas-generating composition such as iron oxide, carbon black and dicyandiamide (DCDA). The gas-generating composition may serve as a substrate for the application of additional layers as described below or, alternately, it may be applied to a substrate with additional layers added thereupon, *i.e.*, above the gas-generant and/or between the generant and the substrate. An exemplary gas-generating composition according to the invention comprises between about 10.0-60.0 wt. % azido-polymer, about 40.0-90.0 wt. % oxidizer, and about 0.5-5.0 wt. % curative.

A further aspect of the invention includes a method of increasing the rate at which the gas-generating composition is ignited and is consumed by forming a thin layer of the gas-generating composition in the inflation device. This thin layer may be formed by preparing a slurry of the gas-generating composition, and, in one embodiment, by spray-coating the slurry onto a substrate to achieve a gas-generating composition preferably having an open-cell structure of solid particles which are connected only at discrete surface contact points and are otherwise separated. Producing the thin layer by spray-coating to form the open-

cell structure is believed to enhance the burning and consumption rate of the gas-generating composition by increasing its surface area. The invention is not limited to such spray-coating, however, and any method which produces the desired result is deemed to be within the scope of the invention. The burning rate enhancement produced by the increased surface area facilitates low pressure combustion and burning of the gas-generating composition. Alternately, in a preferred embodiment, the thin layer of gas-generating propellant composition may instead be formed by using a drawing process wherein the propellant composition is drawn through a notched bar coater across a drawing table to the desired thickness.

In another embodiment of the invention, the combustion rate of the gas-generating composition is facilitated or enhanced by providing one or more thin layers of ignition-enhancing material with high thermal diffusivity adjacent to the gas-generating composition, *e.g.*, above and/or below the gas generating composition. The high thermal diffusivity layer(s) functions by facilitating heat flow through the material to the solid gas-generant. The material of the high thermal diffusivity layer is preferably, but not necessarily, a metallic foil formed from the group of aluminum, stainless steel, gold, silver, copper and their alloys. The high thermal diffusivity layer may partially cover or completely enclose the thin layer of gas-generating material. The high thermal diffusivity layer may also form the substrate for the gas-generating composition. Alternatively, one or more additional high thermal diffusivity layer(s) may enclose both the gas-generating composition layer and a single or set of multiple high thermal diffusivity layer(s) located adjacent thereto.

The objects of the invention are further achieved by a gas generator or inflator of the present invention

having the unique properties of generating gas at a rate of at least 900 liters per second and, preferably, about 3,000 liters per second at combustion pressures of approximately 1000 psi and more preferably 250 psi above atmospheric pressure down to atmospheric or nearly atmospheric pressure. The gas generated by the gas generator is substantially non-toxic and non-noxious and meets the gas pressurization rate of between about 5 and about 24 kPa per msec. when deployed at 21° +/- 3° C as required by the automobile manufacturers. A gas generator according to this embodiment of the invention comprises a gas-generating composition formed into a thin layer and an ignition means associated with the gas-generating composition for initiating the combustion of the gas-generating composition. The gas generator also may contain one or more thin layer(s) of ignition-enhancing material such as the high thermal diffusivity material described above or, in an alternate embodiment, a laminated multilayered foil structure comprised of at least two different materials which release heat by exothermic reaction at a high rate. One non-limiting example of such a multilayered structure comprises alternating layers of MONEL® and aluminum. The reaction rate of the exothermic foil is relatively rapid compared to that of the gas-generant layer so that the entire gas-generant/foil interface is initiated almost instantaneously. The thin layer of gas-generating composition is preferably adjacent to the ignition-enhancing layer and may be spray-coated or drawn onto the thin layer of ignition-enhancing material or alternatively spray-coated or drawn onto a substrate which is bonded to the ignition-enhancing layer.

A further embodiment of the invention comprises an air bag module inflation system having a thin layer of gas-generating composition, ignition means for initiating combustion of the gas-generating composition and a flexible

collapsible material adapted and configured to form a container which is expandable to a predetermined size to collect the gas generated by the combustion of the gas-generating composition at least partially and temporarily. A thin ignition-enhancing layer is preferably provided in physical, direct contact with the gas-generating composition. The gas-generating composition in the air bag module of the invention should be consumed in less than approximately 0.065 seconds or at least a sufficient amount of it to produce enough non-noxious and non-toxic gas to substantially inflate the container formed by the flexible material in the elapsed time between the occurrence of the primary collision and any secondary impacts between the vehicle occupants and the interior of the vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of the outward appearance of a very thin, *i.e.*, compact inflator device constructed according to the invention;

Figure 2 is a sectional view taken along line 2-2 of FIG. 1 illustrating one embodiment of a very thin inflator device according to the invention;

Figure 2A is a sectional view taken along line 2-2 of FIG. 1 illustrating an alternate embodiment of a very thin inflator device according to the invention;

Figure 3 is a photograph of the spray-coated gas-generating composition layer as it appears when magnified 100 times;

Figure 4 is a diagrammatic view of the apparatus for spray application of the gas-generating composition which may be used in forming the inflator of the invention;

Figure 4A is a perspective view of an apparatus which may be used to draw the thin layer of gas-generating material;

Figure 5 is a cross-sectional view of one embodiment of a passive restraint system constructed according to the invention comprising the very thin, compact inflator device coupled with a flexible bag;

Figure 6 is a perspective view of another embodiment of a passive restraint system constructed according to the present invention comprising a variant of the very thin inflator device of FIG. 5 coupled with a flexible bag;

Figure 7 is a perspective view of the inflator device constructed according to Example No. 3; and

Figure 8 is a chart of the pressure history characteristics of the very thin inflator of the invention made according to Example 3 and tested in a sealed fixed volume test tank.

DETAILED DESCRIPTION OF THE INVENTION

While the invention will be described for convenience with reference to passive air bag restraint systems, other fields in which the present very thin, compact inflator would have application include so-called "cargo" munitions wherein a large munition is dropped containing numerous smaller munitions and an ignitable propellant is used to inflate a flexible bag which, upon inflation, disperses the smaller munitions. Moreover, inflators and air bag modules such as those constructed according to the invention may be used as a motive force for ejection seats. Other applications include uses in jet aircraft and the like wherein an air bag is used to position the pilot prior to ejection. Still other applications include inflatable evacuation slides for aircraft, inflatable life rafts, inflatable life vests and inflatable flotation devices. It is further contemplated that embodiments of the invention will have application in military and commercial gas

generators, main propulsion charges and heat sources such as for heating food. The applications described above are provided for the purpose of illustration only and do not limit the scope of the invention.

In all the applications in which the invention may be used, it is required, or at least desirable, that the ignitable propellant combusts, burns or is consumed rapidly. Additionally, it is advantageous that the inflator device be light-weight and compact. In this regard, therefore, the phrase "very thin" as used to describe the inflator refers to the inflator's compactness, particularly its cross-sectional thickness, which permits it to be installed at many locations, *e.g.*, in a motor vehicle door panel where such installations are difficult due to the bulk of the prior art inflator housings. Also, it is desirable to increase the consumption rate or efficiency at which the propellant burns so that there are less reaction byproducts, particularly toxic byproducts.

In general, therefore, the present invention is directed to a compact, *i.e.*, very thin inflator device having a correspondingly thin layer of a gas-generant comprising an azido-polymer, a curing agent and an oxidizer. The gas-generant is capable of rapid combustion without the production of noxious and/or toxic byproducts. The gas-generant is optionally coated, *e.g.*, by spray-coating or drawing, upon a substrate which may be any material which will support and, therefore, physically stabilize the gas-generant. A substrate is not required, however, and the thin layer of gas-generating material may serve as a substrate for the deposition of additional layers, the purpose and features of which are described below.

Ignition means are operatively associated with the gas-generant in order to initiate the combustion thereof. In addition, one or more layers of an ignition-enhancing

material may be deposited above and/or below the gas-generant layer (*e.g.*, between the gas-generant and the substrate, where present). In one embodiment of the invention, the ignition-enhancing material can be a thin layer having a relatively high degree of thermal diffusivity to facilitate the spread of heat from the ignition means. The thin layer which the inflator device may optionally incorporate as an ignition-enhancing material may comprise at least one layer of a metal foil formed, *e.g.*, from aluminum, stainless steel, gold, silver, copper or their alloys. In an alternative embodiment, this material may be provided in the form of a laminated multilayered foil structure formed of at least two different materials which react together in an exothermic reaction to release heat at a rapid rate. Further, in an alternate embodiment, a layer of filtering material may be deposited between the gas-generant and an attached inflatable bag.

Referring initially to FIGS. 1, 2 and 2A, there is illustrated a gas-generating apparatus or device constructed according to the invention in the form of a very thin, compact inflator 10. The inflator 10 is particularly adapted for inflation of a flexible bag operatively associated therewith, known as a passive restraint air bag (see, *e.g.*, Figs. 5-6). In the embodiment shown, inflator 10 comprises five basic components, some of which are optional, which are further described below: (a) an optional substrate 20, (b) an optional ignition-enhancing material 30, (c) a gas-generating propellant composition 40, (d) ignition means 50, and (e) an optional enclosure or outer housing structure 60. The terms gas-generant, gas-generant composition, propellant, gas-generating composition, gas-generating propellant composition and the like are used interchangeably.

As shown in the embodiment illustrated in FIG. 2, a thin layer 41 of solid, ignitable gas-generating propellant

composition 40 is placed adjacent to and in contact with the surface of a thin layer 31 of ignition-enhancing material 30. The gas-generating composition 40 may be deposited on, bonded to or coated directly onto the surface of the thin ignition-enhancing layer 31 as well as to some other supporting material such as substrate 20. It is preferred that the gas-generating layer 41 be formed by a drawing procedure as is well-known in the art (see FIG. 4A discussed below) to deposit the gas-generating composition onto a substrate or, alternatively, the thin ignition-enhancing layer 31. Alternative methods of forming the thin layer of gas-generating material include spray-coating (see FIG. 4), gap or slurry-coating, cast molding, injection molding, coextrusion with the substrate or ignition-enhancing layer, compression molding, calendaring and/or rolling all of which are well-known in the art. The spray-coating deposition process generates an open-cell structure of solid particles which are connected at discrete, limited surface contact points. The remaining portions of the particles are separated by gaps there between which increase the surface area of the gas-generating composition.

More particularly with reference to FIG. 3, under 100x magnification, the surface of the spray coated gas-generating material comprises particles 46 of several different sizes wherein the particles touch adjacent particles at limited contact points and wherein a substantial portion of the surface area of each particle is not in contact with any other particle, *i.e.*, there are gaps between the particle surfaces. Each particle comprises a plurality of spherical-like bodies or nodules of different sizes joined and stuck together in random order resulting in an asymmetrical and irregular shape with a rough surface having a relatively large surface area. The resulting structure is fairly porous and produces a structure which has a bulk

density in the range of 20% to 90% of the theoretical solid bulk density. It is believed that the open-cell structure of the propellant layer increases the burning or consumption rate of the gas-generating composition because of the resulting increased surface area.

The increased surface area allows more gas-generating composition to be involved in the combustion in a shorter time. In particular, it is believed that the burn rate increases because the flame front jumps the gaps between the particles or cell structures. Further, the consumption rate improvement produced by the open-cell structure of the gas-generating composition 40 facilitates its rapid combustion at low pressures.

Alternate structures having increased surface area may be substituted for the thin layer 41 of gas-generating material 40 described above. For example, the gas-generating material 40 may be coated onto a substrate such as a stainless steel or aluminum screen with the screen being bonded to the thin ignition-enhancing layer 31 of ignition-enhancing material 30.

The layer 41 of gas-generating composition 40 should be thin enough so that low bulk burning rate materials can be used. Examples of representative thicknesses for the gas-generating composition layer include approximately 0.01 to approximately 0.25 inches. Of course, as one of ordinary skill in this art would understand, the thickness of the gas-generating composition layer will vary from application-to-application and may be more or less than the exemplary thickness disclosed. In general, however, the layer 41 of gas-generating material 40 should be thin enough so that the surface burning rate and the surface area, but not the bulk burning rate, are the overriding factors controlling the consumption time for a particular gas-generating composition 40. The thin layer 41 of gas-generating composition 40

further may be processed by forming, shaping, stamping or cutting tablets 45 or other shapes from the thin layer of gas-generating composition.

Referring again to FIGS. 2 and 2A, a thin layer 31 of ignition-enhancing material 30 may be provided which is applied to, deposited on or bonded to the internal, *i.e.*, upper surface of substrate 20. As used herein, the terms "upper" or "above" as used in reference to the laminated structure of the claimed inflator device mean on top of, whereas "lower" refers to a bottom surface of a layer or stack of layers. Optional substrate 20 which also may be referred to as a "mounting plate" may be formed of any material capable of supporting the propellant and optional ignition-enhancing composition such as metal, plastic or a composite and may be configured into any convenient shape. The material used in forming substrate 20 is selected for the weight-strength characteristics required for the particular application. The ignition-enhancing material 30 may be vapor-deposited, powder-coated, electroplated or adhesively bonded onto the substrate. Other fabrication processes known in the art are also possible to achieve the same result. Depending upon the desired performance characteristics or requirements, the ignition-enhancing layer 31 may be continuous or discontinuous such as in a discontinuous pattern.

It is further contemplated that in another embodiment of the invention the thin layer 31 of ignition-enhancing material 30 may act as the substrate 20. The thin layer 31 of ignition-enhancing material 30 is located adjacent to the gas-generating composition 40 and, preferably, is in direct contact with the gas-generating composition 40. The gas-generating composition 40 may be deposited on, bonded to, spray-coated or drawn onto the thin layer 31 of ignition-enhancing material 30.

The thin layer 31 of ignition-enhancing material 30 is added for the purpose of enhancing the ignition, the consumption and the combustion (burning) rate of the solid gas-generating composition 40. Increasing the burning rate results in more efficient combustion of the gas-generating composition with the additional benefit of producing lower quantities of toxic byproducts. Increasing the combustion efficiency or burning rate of the gas-generating composition allows the inflator of the present invention to operate at lower pressures. Accordingly, pressure vessels and/or other structural components may be unnecessary or made lighter and/or more compact in these inflators.

One embodiment of the thin layer 31 of ignition-enhancing material 30 comprises a single thin layer of a material having high thermal diffusivity. The ignition-enhancing material 30 of the subject embodiment is typically a metallic material and may be incorporated in the form of a "foil". The layer of ignition-enhancing material 30 is preferably provided as a continuous sheet. As an alternative, however, the ignition-enhancing material may be provided in a pattern, for example, a discontinuous pattern of metal foil or as a woven screen. The ignition-enhancing layer may also comprise one or more thin layers having high thermal diffusivity as illustrated in FIG. 2A as 31a, 31b. The layers, *e.g.*, 31a, 31b may be deposited above and/or below the layer of the gas-generating composition. Preferably, the gas-generating composition 40 is in contact with the ignition-enhancing material 30, more preferably it is applied and/or bonded to the ignition-enhancing layer and most preferably, it is deposited by a drawing procedure (FIG. 4a) onto the ignition-enhancing layer.

The single thin layer 31, or alternately the thin layers, increase(s) the ignition and consumption rate of the solid gas-generating composition 40. In particular, it is

believed that the ignition and the flame-spreading rate of the solid gas-generating composition is increased by heat flow through the ignition-enhancing material into the unreacted solid gas-generant composition. It is believed also that ignition is enhanced by a localized pressure increase caused by the close proximity of the ignition-enhancing material to the solid gas-generating composition burning surface. Flow restrictions near the material surface result in elevated pressure in the region of the interface between the ignition-enhancing material and the unreacted solid gas-generating composition.

The primary factor influencing the suitability of a material for use as an ignition-enhancing layer is its thermal diffusivity. The thermal diffusivity of the ignition-enhancing material 30 must be higher than the thermal diffusivity of the gas-generating composition 40 in order to obtain combustion, consumption and ignition rate enhancement of the gas-generating composition. The higher the diffusivity, the better the heat conductor and its chances of being suitable as an ignition-enhancing layer. Representative values of thermal diffusivity which have been found to have beneficial rate increasing effects are greater than about 0.2 cm^2/second but these values are not a limiting threshold value. Typically, thin layers or foils of metal material may be used. In the case of foils, aluminum foil, copper foil, silver foil or gold foil may be used. Alternately, combinations of these or other equivalent (*i.e.*, in terms of thermal diffusivity) materials formed into thin layers are suitable as the ignition-enhancing layer 31 providing they have an acceptable thermal diffusivity value. By utilizing an ignition-enhancing material 30 having a thermal diffusivity higher than the gas-generating material 40, a large surface area of the gas-generating material layer 41 and ignition-enhancing layer 31 interface is initiated

almost instantaneously thus reducing the action time of the inflator. In a still further embodiment, thin layers of non-metallic material with proper thermal diffusivity properties likewise may be used. The thickness of the foil layers may range anywhere from a fraction of a thousandth of an inch to several thousands of an inch (*i.e.*, 0.0001-0.009 inches).

In another embodiment, illustrated in FIG. 2A, a single layer 31c or multiple layers 31c, 31d of ignition-enhancing material may cover or enclose the thin layer(s) of ignition-enhancing material 31a, 31b and the thin layer 41 of gas-generating propellant 40. Heat flow through the ignition-enhancing layer and a nearly one-dimensional flow of hot gases between the parallel layers of the propellant and the ignition-enhancing layer results in substantial increases in the burning rate of the gas-generating composition. In another embodiment (not shown), a single layer or multilayers of ignition-enhancing layer(s) may cover or enclose only the solid gas-generating composition layer 41, without ignition-enhancing layers 31a, 31b. In still other embodiments of the invention, alternating layers 31 of ignition-enhancing material 30 and layers 41 of gas-generating material 40 may be used.

Another form which the ignition-enhancing material 30 may take involves the use of a laminated multilayer structure which releases heat (rather than simply transferring the heat from the initiator means) by a high rate exothermic chemical reaction. In the subject embodiment, a multilayered continuous sheet of reactive inter-metallic pairs of materials such as aluminum and nickel or high propagation rate thermite-type reaction materials are utilized. An example of a suitable thermite reaction is one involving aluminum and iron oxide which react to form aluminum oxide and iron with the release of energy. One such multilayer structure which has been successful is formed by

vapor depositing alternating layers of Monel® (trade name for an alloy of nickel, copper, iron and manganese) and aluminum. Approximately two hundred and fifty (250) layers of Monel® and aluminum are deposited, with each Monel® layer being approximately 16 nanometers (nm) thick and each aluminum layer being approximately 24 nm thick, resulting in a total multilayer structure having a thickness of approximately 0.010 mm (or 0.0004 inches).

This laminated multilayer structure provides enhancements comparable to those described for the thin metallic foil. In addition, however, as noted above, the structure provides energy to the unreacted solid gas-generant composition surface. When a localized area of the multilayered structure is heated above a critical temperature, the two metals diffuse into each other. The diffusion process is exothermic, increasing the surface temperature approximately 1200° C and self-propagating into the unreacted material. This results in a linear ignition rate of the gas-generating composition material which is approximately equal to the linear reaction propagation rate of the multilayered structure. Typically, the linear propagation rate of the exothermic laminated multilayered thin ignition-enhancing layer 31 will be from about 5 to about 15 meters per second (about 200 to about 600 inches per second) with the described nickel and Monel® multilayered structure having a reaction front propagation rate of approximately 10 meters per second (approximately 400 inches per second).

Tens to hundreds of alternating pairs of very thin layers of reactive materials may be used. The properties which determine the suitability of such reactive pairs as an exothermic ignition-enhancer are the speed or propagation rate of the exothermic front and the amount of energy released.

In a test illustrating the burning rate enhancement effect of the thin layer 31 of ignition-enhancing material 30, hand-cast solid gas-generating material consisting of 15 wt % glycidyl azide polymer, 80 wt % potassium perchlorate, 4 wt % dicyandiamide and 1 wt % iron oxide (Pyrocat®) were hand-mixed as a slurry, hand-cast into a sheet 0.030 inches thick and cured in an oven at 145°F for 45 minutes. The resultant material was ignited at atmospheric pressure and room temperature and had a burning rate of 1.51 inches per second. In comparison, the same formula of GAP gas-generating composition prepared in the same manner and to the same thickness as the first sample and placed on a layer of the laminated multilayered ignition-enhancing material of Monel® and aluminum described above with a second layer of the same ignition-enhancing material placed on top was cured and ignited under the same conditions and had a burning rate of 2.73 inches per second.

In a test of a different embodiment, a gas-generating composition comprising glycidyl azide polymer (GAP) Polyol, an oxidizer and a curing agent were spray-coated onto .0015 inch thick aluminum foil measuring 0.25 inches wide by 4.0 inches long and ignited at atmospheric pressure and burned at 7 inches per second. The same gas-generating composition covered with multiple layers of aluminum foil enhanced the burning rate from 7 inches per second to an effective rate of 900 inches per second.

A nichrome, *i.e.*, "hot" wire 50 has been successfully used as the igniter or ignition means to initiate the reaction within solid, gas-generating composition 40 or, alternately, within the thin layer 31 of ignition-enhancing material 30, which in turn initiates the solid gas-generating composition 40. This ignition source is only one example and any ignition source capable of starting the reaction in the thin layer of ignition-enhancing material

30 or solid gas-generating composition 40 on command is suitable. Any such device which would provide the required function thus is considered within the scope of the invention. Standard automotive air bag initiators and semiconductor bridge devices are examples of other potential means for starting these reactions. For example, a semiconductor bridge igniter with a non-conductive layer between the igniter and ignition-enhancing material 30 would be capable of starting the reaction within the ignition-enhancing layer 31.

In FIGS. 1, 2 and 2A, a thin metal or non-metal enclosure structure or housing 60 may be included in order to at least partially surround and therefore protect the internal components of the inflator 10, *i.e.*, during shipping, handling and installation. Moreover, it is contemplated that a portion of or the entire enclosure structure 60 can serve as the substrate 20 onto which layer 41 of gas-generating material 40 and/or ignition-enhancing material 30 may be deposited. An optional feature of the enclosure structure 60 is a mounting flange 65 which facilitates attachment of the inflator 10 to, for example, an air bag.

A desirable feature of the inflator of the invention is that the gas-generating material exhibits a high consumption rate preferably at a pressure of from about 1000 psi above atmospheric pressure, more preferably from about 250 psi above atmospheric pressure and ideally down to nearly one atmosphere of pressure (*i.e.*, about 20-10 psi). For example, for use in air bag applications, the consumption rate must be fast enough to consume the gas-generating composition in the brief time allowed for activation of the air bag system. Since an air bag typically must be inflated fully in 0.015 to 0.100 seconds, the gas-generating material must be consumed between 0.007 and 0.025 seconds

(approximately 7-25 milliseconds). Importantly, the amount of gas-generating material consumed within this time must be sufficient to generate enough gas to fill the bag or other associated gas-containing receptacle. For driver's side air bag applications, this is typically on the order of about 60 liters. For some applications, such as passive restraint air bag systems, it also is required that the gas-generating composition 40 produce low toxic gas. As used herein, the phrases "low toxic gas", "low gas toxicity", "non-toxic and non-noxious gas", "substantially non-toxic and non-noxious" and their equivalents refer to the ability of the gas to meet toxicity requirements for use in an automotive air bag inflation system, such as, for example, the specification for a 100 cubic foot compartment provided by the automotive manufacturers. It is desirable also that the gas-generating composition incorporate a low solids oxidizer system to minimize solids on combustion and an energetic binder capable of supporting atmospheric pressure combustion.

The gas-generating composition comprises a hydroxyl functional azido-polymer, preferably Glycidyl Azide Polymer (GAP) available, *e.g.*, from 3M Corporation of St. Paul, Minnesota. GAP has the ability to sustain combustion without the addition of any oxidizers which permits a wide selection of oxidizers and promotes easy ignition at low pressure. It is contemplated that other azide polymers, with or without hydroxyl groups, can serve as the gas-generating composition in combination with a curative and oxidizer to form a gas-generating composition.

The gas-generating composition may contain approximately 10-60 weight percent (wt. %) azido (preferably glycidyl azide) polymer, approximately 40.0-90.0 wt. % oxidizer, and approximately 0.5-5.0 wt. % curing agent. Optionally, as discussed below, the gas-generating composition may also contain 0.0-5.0 wt. % iron oxide, and

0.0-2.0 wt. % carbon black. More preferably, the gas-generating composition may comprise from about 15.0-25.0 wt. % azido polymer, 1.0-2.5 wt. % curing agent, 60.0-80.0 wt. % oxidizer, 1.0-3.0 wt. % iron oxide and 0.0-1.0 wt. % carbon black.

An acrylate may be used as the curative for the GAP fuel. Tetraethylene glycol diacrylate made by Aldrich Chemical Co., Inc. as TTEGDA is the preferred acrylate although pentaerythritol diacrylate, pentaerythritol triacrylate, and pentaerythritol tetraacrylate made by the Sartommer Corporation as SR-444 and polyethyleneglycol diacrylate made by the Sartomer Corporation as SR-344 also have worked well. Other curatives include 1,6 hexanediol dimethacrylate. Acetyl triethyl citrate such as Citroflex A2 from Morflex has also worked in combination with TTEGDA as a plasticizer. Other additives may include Aromatic Trifunctional Aziridine 3M brand bonding agent HX-868 or HX-752.

Potassium perchlorate, potassium nitrate, sodium nitrate, lithium nitrate, lithium carbonate, ammonium perchlorate, ammonium nitrate, calcium nitrate, ceric ammonium nitrate, magnesium nitrate, sodium perchlorate or lithium perchlorate as well as combinations of these may be used as the oxidizer. To meet the toxicity requirements for air bag applications, any amount of ammonium perchlorate used should be offset by an equal molar amount of potassium nitrate, sodium nitrate, lithium nitrate or lithium carbonate. Different amounts and combinations of the oxidizer are selected in a manner known in the art to tailor the performance and handling characteristics of the gas-generant composition such as, for example, burning rate and composition of gaseous output. The amount of oxidizer, for example potassium nitrate, sodium nitrate, ceric ammonium nitrate, lithium nitrate, lithium carbonate, potassium

perchlorate, lithium perchlorate, sodium perchlorate and ammonium perchlorate, added to the gas-generating material of the invention can range up to about 90.0 wt. %.

A variety of optional ingredients may be added as noted above to serve as modifiers to adjust the performance and handling characteristics of the gas-generant composition. These additional ingredients may include, for example, iron oxide which is used as a burning rate catalyst, carbon black which is used as a thickening agent and dicyandiamide (DCDA) which is included as a burning rate modifier. DCDA increases the burning rate and lowers the gas toxicity, and carbon black helps to maintain the solids in suspension long enough to permit spray-coating. Nanocat®, also known as Pyrocat®, trade names of iron oxide commercially available from Mach 1 Company, have been used successfully in formulating a gas-generating composition. The chart below indicates an exemplary gas-generating composition according to the invention including the approximate lower and upper limits of the various components.

INGREDIENT	LOWER APPROXIMATE LIMIT (WT. %)	UPPER APPROXIMATE LIMIT (WT. %)
GAP	10.0	60.0
oxidizer	40.0	90.0
curative	0.5	5.0
iron oxide	0.0	5.0
carbon black	0.0	2.0
dicyandiamide	0.0	10.0

One exemplary gas-generating composition comprises:

INGREDIENT	WT. %
GAP	23.26
TTEGDA (Tetraethylene glycol diacrylate)	1.63
Ammonium Perchlorate, AP	40.26
Sodium Nitrate	32.35
Iron Oxide, Fe_2O_3	2.00
Carbon Black	0.50
Total	100.00

A further exemplary gas-generating composition comprises:

INGREDIENT	WT. %
Glycidyl Azide Polymer, GAP	21.30
TTEGDA	1.63
Ammonium Perchlorate, AP	44.92
Lithium Nitrate	27.98
Iron Oxide, Fe_2O_3	2.00
Citroflex	1.67
HX-868	0.50
Total	100.00

One method of depositing the thin layer of gas-generating material is by preparing the gas-generating material as a slurry and spray-coating it onto a substrate. One method of preparing the slurry is by mixing the gas-generating fuel with a solvent and a solvent-curing material. Figure 4 is a diagrammatic illustration of the method and apparatus used to spray-coat a substrate 130 with a slurry of the gas-generating composition 40. In Figure 4, spraying apparatus 120 includes a motionless mixer 150 to mix the gas-

generating composition ingredients to form the slurry and a spray-head 140 which sprays the gas-generating composition slurry onto a substrate 130 which can be, for example, the thin layer 31 of ignition-enhancing material 30 described herein. There are three feed lines into the motionless mixer 150. A first feed line 160 supplies the glycidyl azide polymer (GAP) and a solvent, which may be, for example, either methylene chloride and/or xylene, to the mixer. A second feed line 170 supplies the polymer solid components, *i.e*, the oxidizers (potassium perchlorate, potassium nitrate, sodium nitrate, lithium nitrate, lithium carbonate and ammonium perchlorate to name but a few), the burning rate catalyst (iron oxide), the thickening agent (carbon black), and the burning rate modifier (DCDA) to the mixer 150. A third feed line 180 supplies the curing agent (acrylate) to the mixer 150. Either or both of the second and third feed lines 170, 180 also may include a solvent such as methylene chloride and/or xylene. There may be one or several spraying apparatus 120 so that if desired, multiple layers may be applied.

After the gas-generating composition slurry has been sprayed onto the substrate 130, the substrate 130 is transported by conveyor belt 185 to a drying station 190 where the gas-generating composition slurry is cured to form a thin layer 41 of solid gas-generating composition 40. The substrate 130 with the thin layer of gas-generating composition 40 are thereafter transported by belt 185 to a cutting station 195 where it is cut to size. If the GAP gas-generating composition is first applied to a substrate such as a screen, the substrate may be bonded adhesively to the ignition-enhancing layer, for example, with a glycidyl azide polymer-based lacquer.

The resulting structure is fairly porous and has a bulk density in the range of 20% to 90% of the theoretical

solid bulk density. Particle sizes vary from .003 microns for iron oxide, to less than 1 micron for carbon black, to 2 microns for potassium perchlorate to 50 microns for potassium nitrate.

A preferred method of preparing the thin layer of gas-generating composition is by using a drawing process. The drawing process does not produce the porous structure of the spray-coating process and the density of the resulting thin layer approaches the theoretical bulk density of the gas-generating composition. FIG. 4A depicts an apparatus 200 used in drawing the gas-generating composition. The apparatus in FIG. 4A includes a drawing table 205, a notched bar-coater 210 and a pair of micrometer screws 215, 220. Because of the explosive nature of the gas-generating composition, all the drawing equipment should be grounded. In operation, the micrometer screws 215, 220 on the drawing table 205 are adjusted to control the desired thickness of the gas-generating composition 225 taking into consideration the thickness of an antistatic film 230 upon which the gas-generating composition is supported and the ignition-enhancer layer 227 upon which it is drawn. Antistatic film is laid on the drawing table and inserted under the notched bar-coater. The ignition-enhancer layer 227 is taped down on the antistatic film in preparation for drawing the gas-generating composition thereupon.

The gas-generating composition is first mixed in a slurry form. A small quantity of the slurry of the gas-generating composition is placed directly behind the notched bar-coater 210. The antistatic film 230 is pulled level with the drawing table 205 by grasping the edge of film 230 until the gas-generating composition slurry is drawn on the ignition-enhancer layer 227. Exemplary thicknesses for the drawn gas-generating composition layer are from about 15 to about 40 mils.

Thereafter, the antistatic film 230 with the ignition-enhancer layer 227 and the gas-generating layer 225 drawn thereon is cut. The layered material is then removed from table 205 and cured after which the antistatic film is removed from the back side of the ignition-enhancer layer 227.

FIG. 5 illustrates an air bag passive restraint system 70 according to the invention. The embodiment of FIG. 5 is constructed of the same components as illustrated and described with regard to FIGS. 1, 2 and 2A with the exception of the enclosure structure. In FIG. 5, the enclosure structure is replaced by a module structure which comprises a thin metal or non-metal mounting plate 85 used to attach the inflator 10 to the air bag 90. The mounting plate 85 also provides a mounting surface for attachment of the inflator-air bag assembly to the vehicle.

Air bag 90 is formed from a flexible bag material 95 which is attached to the mounting plate by, for example, an adhesive bond 96 or, alternatively, with fasteners or other clamping means (not shown). Air bag 90 may be of unitary construction or alternatively comprise more than one piece of flexible bag materials 95 which may be adhesively bonded such as at 98, or alternatively, sewn. The air bag 90 is adapted so that it can be folded into a tight package which covers the components of the inflator such as ignition-enhancing material 30, solid gas-generating composition 40 and at least a portion of ignition means 50. The air bag 90 is expanded to the desired configuration upon combustion of the gas-generating composition elements which fill the air bag with gas.

In the case of air bag passive restraints, it is desirable to deflate the bag as soon as the secondary impact of the accident is completed so that the occupants' exit from the vehicle is not disrupted by an inflated air bag. Also,

it is desirable to deflate the bag rapidly so that in the case of accidental inflation, the distraction to the driver is sufficiently brief so that control of the vehicle may be maintained. Air bag 90 thus may be provided with vents (not shown) to control the air bag's inflating and deflating performance.

An optional layer(s) of flexible insulation/filtration media 80 may be used to create a barrier between the solid gas-generating composition 40 and the inner surface of the air bag material 95. The insulation/filtration media 80 may be a felted refractory cloth of aluminum and silicon oxide which can be bonded adhesively or otherwise attached to the solid gas-generating composition 40 on one side and/or the bag material 95 on the other. The insulation/filtration media 80 may be required as a heat shield to protect the bag material from direct flame impingement or excessive heat during combustion of the solid gas-generant. The insulation/filtration media 80 also may be designed to function as a filter to prevent solid particles created by the combustion of the propellant from exiting the air bag.

Using the structure and components described above, an air bag module 70 can be packaged in a total thickness of less than approximately 0.25 inches. Such an air bag module 70 is sufficiently thin to permit its placement, for example, between the decorative interior trim of a passenger door and the door structure or to conform to the interior surface trim of an A or B pillar in a passenger vehicle.

FIG. 6 illustrates a different embodiment of inflation system 70. System 70 of FIG. 6 uses the inflator construction of FIGS. 1 and 2 with a flexible passageway 75 formed in the enclosure 60 connected to an air bag 90. System 70 of FIG. 6 optionally may include the insulation/filtration media 80 in the enclosure 60 to protect

the passageway 75 or air bag material 95 from the heat and particles generated during the combustion of the gas-generating composition. The embodiment of FIG. 6 or a similar arrangement may be desirable when the pressure during the combustion of the gas-generating composition may be excessive for the air bag 90.

The following examples illustrate various methodologies for preparing the gas-generating composition and constructing the inflation device of the invention. These examples are provided for the purpose of illustration only and do not limit the invention in any manner.

EXAMPLE NO. 1

Three aluminum screens, each 1.0" x 1.4" and .022" thick having a weave pattern of 18 x 13 per square inch (with openings .030 x .050 inches), were dipped in a mixture of 20 grams of gas-generating propellant with 15 grams of methylene chloride solvent.

The propellant composition was composed of:

Ingredient	Weight Percent
GAP	17.33
SR444® Acrylate	1.30
Potassium Perchlorate Oxidizer	63.62
DCDA	4.00
Nanocat®	2.00
Carbon Black	0.50
Potassium Nitrate	11.25

The propellant solids were ball-milled by enclosing them in a container and rolling for an hour. The first two screens were dipped twice and hung to dry, then dipped a third time and while wet, the screen was laid on a foil. The foil is the exothermic ignition-enhancer described earlier as having 250 alternating layers of 16 nm thick Monel® and 24 nm thick aluminum, the foil having a total thickness of 0.0004 inches. The two foil layers were each 1.0" x 1.9" and weighed between

0.17-0.15 grams. The third screen was dipped once in the gas-generating composition mixture and arranged so that the final configuration comprised alternating layers of three screens and two foils. A total of 2.5 grams of propellant was used on the three screens. A coil ignition wire was attached with a small bead of epoxy. A 5" x 5" x 10" bag was folded and held in place. The specimen was ignited and inflated the bag. Maximum pressure was 2.8 psi above atmospheric pressure.

EXAMPLE NO. 2

Aluminum screens as described in Example No. 1 were dipped in a mixture of 8.5 grams of methylene chloride solvent and 10 grams of the propellent composition described in Example No. 1. The propellant solids were screened through a 70 mesh screen in addition to the ball-milling described in Example No. 1. A total of three screens were utilized. Each was dipped twice and hung to dry. The screens were then dipped a third time and while wet, the screens were laid between the two foil layers as described in Example No. 1. A total of 3.27 grams of propellant was used on the screens. A 5" x 5" x 10" bag was folded and held in place. The specimen was ignited and inflated the bag. The maximum bag pressure was 5 psi above atmospheric pressure.

EXAMPLE NO. 3

Ten (10) aluminum foil disks 66 mm in diameter and 0.04 mm thick were coated on one side with the propellant described in Example No. 2. The spray-coating was approximately .040 inches (1.02 mm) thick with an average layer density of 0.65 g/cc. Total propellant weight was 25.17 grams. As shown in FIG. 7, these ten (10) disks 235 were stacked with nine (9) alternating disks (not shown) of stainless steel screen (66 mm in diameter). The assembled

stack was held together by four tie bolts 240, 245, 250, 255 which held two perforated square pieces of .080 inch (2 mm) thick stainless steel 260, 265 in tension (see FIG. 7). A nichrome ignition wire 270 was attached to the top disk in the vertical stack near the disk's outside diameter. The stack assembly was sealed in a 28 liter test vessel (not shown) equipped with means for functioning the ignition wire and measuring the pressure resulting from consumption of the propellant. Figure 8 depicts the pressure time history produced by this gas generator. The maximum closed tank pressurization rate of the pressure time history shown in Figure 8 is 16.53 kPa per msec. In general, automobile manufacturers specify that inflators produce pressurization rates between about 5 and about 24 kPa per msec. when deployed at approximately atmospheric pressure at 21° +/- 3° C. The test data shows that the device tested generates gas at a rate and toxicity approximating that needed to meet air bag inflator capability requirements.

The foregoing description, figures and examples of the different embodiments is provided only to illustrate various configurations and applications of the present invention. Many modifications and variations on the embodiments may be made without departing from the spirit and scope of the invention as indicated by the appended claims.

CLAIMS

WE CLAIM:

1. A pyrotechnic gas-generating composition comprising:

an azido polymer;
a curing agent; and
an oxidizer

wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 1000 psi above atmospheric pressure, at least about 900 liters per second of a substantially non-noxious and non-toxic combustion product.

2. The composition of claim 1 wherein the polymer is glycidyl azide polymer (GAP) and wherein said polymer is present in the composition in an amount of from about 10 to about 60 weight percent.

3. The composition of claim 1 wherein the curing agent is an acrylate and wherein said acrylate is present in the composition in an amount of from about 0.5 to about 5 weight percent.

4. The composition of claim 3 wherein the acrylate is selected from the group consisting of tetraethylene glycol diacrylate, pentaerythritol diacrylate, pentaerythritol triacrylate, pentaerythritol tetraacrylate, polyethylene glycol diacrylate and mixtures thereof.

5. The composition of claim 1 wherein the curing agent is selected from the group consisting of mixtures of tetraethylene glycol diacrylate, pentaerythritol diacrylate,

pentaerythritol triacrylate, pentaerythritol tetraacrylate, polyethylene glycol diacrylate, 1,6 hexanediol dimethacrylate and mixtures thereof.

6. The composition of claim 1 wherein the oxidizer is present in the composition in an amount of from about 40 to about 90 weight percent and wherein said oxidizer is selected from the group consisting of at least one of potassium perchlorate, potassium nitrate, sodium nitrate, lithium nitrate, lithium carbonate, ammonium perchlorate, ammonium nitrate, calcium nitrate, ceric ammonium nitrate, magnesium nitrate, sodium perchlorate, lithium perchlorate and mixtures thereof.

7. The composition of claim 1 which further comprises at least one additional additive material selected from the group consisting of up to about 5 weight percent of iron oxide, up to about 2 weight percent of carbon black and up to about 10 weight percent of dicyandiamide.

8. The composition of claim 1 comprising:

from about 10 to about 60 weight percent of glycidyl azide polymer;

from about 40 to about 90 weight percent of the oxidizer; and

from about 0.5 to about 5 weight percent of the curing agent.

9. The composition of claim 8 which further comprises at least one additional additive material selected from the group consisting of up to about 5 weight percent of iron oxide, up to about 2 weight percent of carbon black and up to about 10 weight percent of dicyandiamide.

10. The composition of claim 8 wherein said glycidyl azide polymer is present in an amount of from about 15 to about 25 weight percent of said composition.

11. The composition of claim 8 wherein said oxidizer is present in an amount of from about 60 to about 80 weight percent of said composition.

12. The composition of claim 8 wherein said curing agent is present in an amount of from about 1.0 to about 2.5 weight percent of said composition.

13. An inflator device comprising a gas-generating composition, said gas-generating composition comprising:

an azido polymer;
a curing agent; and
an oxidizer

wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 1000 psi above atmospheric pressure, at least about 900 liters per second of a substantially non-noxious and non-toxic combustion product.

14. The inflator device of claim 13 wherein said gas-generating composition is provided in the form of at least one relatively thin layer.

15. The inflator device of claim 14 wherein the thickness of each said gas-generating composition layer is from about 0.01 to about 0.25 inches.

16. The inflator device of claim 14 wherein the thin layer is in the form of an open-cell structure of particles, said particles connected to adjacent particles at

discrete surface contact points such that the thin layer is in the range of approximately 20% to 90% of its theoretical solid bulk density.

17. The inflator device of claim 13 which further comprises a substrate for supporting the gas-generating composition.

18. The inflator device of claim 13 further comprising at least one layer of an ignition-enhancing material adjacent to and in contact with at least a portion of said at least one layer of gas-generating composition.

19. The inflator device of claim 18 which further comprises a substrate beneath the gas-generating composition and wherein the ignition-enhancing material is interposed between the substrate and the gas-generating composition.

20. The inflator device of claim 18 wherein said ignition-enhancing material is at least one layer of a metallic foil.

21. The inflator device of claim 20 wherein the metallic foil is formed from a metal selected from the group consisting of aluminum, gold, stainless steel, silver, copper and their alloys.

22. The inflator device of claim 20 wherein the thickness of each said foil layer ranges from about 0.0001 to about 0.009 inches.

23. The inflator device of claim 18 wherein said ignition-enhancing material comprises at least one layer of a material having a relatively high degree of thermal

diffusivity sufficient to facilitate heat flow through said ignition-enhancing material to the layer of pyrotechnic gas-generating composition, said at least one layer deposited above and/or below the gas-generating composition.

24. The inflator device of claim 23 wherein said ignition-enhancing material has a thermal diffusivity of at least about 0.2 cm^2/second.

25. The inflator device of claim 23 wherein the gas-generating composition is bonded to a screen and wherein the screen is bonded to at least one layer of said ignition-enhancing material.

26. The inflator device of claim 23 wherein said ignition-enhancing material is present as a continuous layer.

27. The inflator device of claim 23 wherein said ignition-enhancing material is present as a discontinuous layer.

28. The inflator device of claim 27 wherein said ignition-enhancing material is in the form of a woven screen.

29. The inflator device of claim 18 wherein said ignition-enhancing material comprises a laminated multilayered continuous sheet structure of alternating reactive pairs of metals which react with each other exothermically to produce sufficient heat to enhance combustion of the gas-generating composition.

30. The inflator device of claim 29 wherein the reactive metal pairs are comprised of aluminum and nickel, respectively.

31. The inflator device of claim 29 wherein the reactive metal pairs are comprised of aluminum and iron oxide, respectively.

32. The inflator device of claim 29 wherein the reactive metal pairs are comprised of aluminum and an alloy of nickel, copper, iron and manganese, respectively.

33. The inflator device of claim 29 wherein the multilayered sheet structure has a thickness of up to about 0.010 mm.

34. The inflator device of claim 13 wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 250 psi above atmospheric pressure, at least about 900 liters per second of a non-noxious and non-toxic combustion product.

35. The inflator device of claim 13 which further comprises means for initiating combustion of said gas-generating composition.

36. The inflator device of claim 35 wherein said combustion initiating means is selected from the group consisting of a semiconductor bridge ignitor, a nichrome wire and an automotive air bag squib initiator device.

37. A compact inflator device comprising:

a substrate configured and adapted for supporting at least one layer of an ignition-enhancing material;

at least one layer of an ignition-enhancing material upon an upper surface of said substrate, said ignition-enhancing material having a sufficient degree of thermal diffusivity to facilitate heat flow therethrough to an adjacent layer of a gas-generating composition; and

at least one thin layer of a gas-generating composition upon an upper surface of said ignition-enhancing material, said gas-generating composition comprising:

an azido polymer;
a curing agent; and
an oxidizer

wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 1000 psi above atmospheric pressure, at least about 900 liters per second of a substantially non-noxious and non-toxic combustion product.

38. The inflator device of claim 37 wherein the azido polymer is a glycidyl azide polymer present in an amount of from about 10 to about 60 weight percent, the oxidizer is present in an amount of from about 40 to about 90 weight percent and the curing agent is an acrylate, said acrylate present in the composition in an amount of from about 0.5 to about 5 weight percent.

39. The inflator device of claim 37 wherein the gas-generating composition further comprises at least one additional additive material selected from the group consisting of up to about 5 weight percent of iron oxide, up to about 2 weight percent of carbon black and up to about 10 weight percent of dieyandiamide.

40. The inflator device of claim 37 which further comprises means for initiating combustion of said gas-generating composition.

41. The inflator device of claim 40 wherein said combustion initiating means is selected from the group consisting of a semiconductor bridge ignitor, a nichrome wire and an automotive air bag squib initiator device.

42. The inflator device of claim 37 which further comprises a housing configured to at least partially surround and protect said gas-generating composition.

43. The inflator device of claim 42 which further comprises mounting means adapted for coupling an inflatable envelope to said housing in operative association with said inflator device.

44. The inflator device of claim 43 wherein said mounting means comprises a flange extending from the outer surface of said housing.

45. The inflator device of claim 43 further comprising an inflatable envelope operatively associated with said inflator, said envelope mounted to the inflator device by said mounting means.

46. The inflator device of claim 45 which further comprises at least one layer of a flexible filtration and insulating material interposed between the gas-generating composition and the inflatable envelope.

47. The inflator device of claim 46 wherein said flexible filtration and insulating material is a felted refractory material.

48. The inflator device of claim 38 wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 250 psi above atmospheric pressure, at least about 900 liters of a substantially non-noxious and non-toxic combustion product.

49. The inflator device of claim 37 wherein at least one layer of the ignition-enhancing layer is a metallic foil formed from a metal selected from the group consisting of aluminum, stainless steel, gold, silver, copper and their alloys.

50. The inflator device of claim 37 wherein at least one layer of the ignition-enhancing material comprises a multilayered sheet structure of alternating reactive pairs of material which react with each other exothermically to produce sufficient heat to enhance combustion of the gas-generating composition.

51. A vehicle occupant passive restraint system comprising:

a) a compact inflator device comprising

an outer housing comprising means for securing an inflatable envelope to said housing which, upon inflation, is configured and adapted to substantially protect a vehicle occupant from injury in the event of a collision involving said vehicle,

at least one relatively thin layer of a gas-generating composition located within said housing, said gas-generating composition comprising:

an azido polymer;
a curing agent; and
an oxidizer

wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 1000 psi above atmospheric pressure, at least about 900 liters per second of a substantially non-noxious and non-toxic combustion product,

at least one layer of an ignition-enhancing material in contact with said gas-generating composition, said ignition-enhancing material having a sufficient degree of thermal diffusivity to facilitate heat flow therethrough and into said gas-generating composition, and

means for initiating combustion of the gas-generating composition; and

b) an inflatable envelope mounted upon said housing by said securing means and operatively associated with said compact inflator device, wherein the envelope is inflated in an approximately atmospheric pressure environment upon combustion of said gas-generating material.

52. The restraint system of claim 51 wherein said gas-generating composition comprises:

from about 10 to about 60 weight percent of a glycidyl azide polymer;

from about 40 to about 90 weight percent of the oxidizer; and

from about 0.5 to about 5 weight percent of the curing agent.

53. The passive restraint system of claim 51 wherein said gas-generating composition is provided as an open cell layer comprised of a plurality of particles oriented such that adjacent particles are in contact with each other at discreet surface points.

54. The restraint system of claim 51 wherein said compact inflator device further comprises a substrate supporting said ignition-enhancing material.

55. The restraint system of claim 51 wherein said ignition-enhancing material comprises a multilayered sheet structure of alternating reactive pairs of materials which react with each other exothermically to produce sufficient heat to enhance combustion of the gas-generating composition.

56. The restraint system of claim 55 wherein the reactive metal pairs are comprised of aluminum and nickel or its alloys, respectively.

57. The restraint system of claim 55 wherein the reactive material pairs are comprised of aluminum and iron oxide, respectively.

58. The restraint system of claim 51 wherein at least one layer of the ignition-enhancing layer is a metallic foil formed from a metal selected from the group consisting of aluminum, stainless steel, gold, silver, copper and their alloys.

59. The restraint system of claim 51 which further comprises at least one layer of a flexible filtration and insulating material interposed between the gas-generating composition and the inflatable envelope.

60. The restraint system of claim 59 wherein said flexible filtration and insulating material is a felted refractory cloth material of aluminum and silicon oxide.

61. The restraint system of claim 51 wherein said inflatable envelope is an air bag.

62. The restraint system of claim 52 wherein the curing agent is an acrylate.

63. The restraint system of claim 52 wherein the polymer, the oxidizer and the curing agent are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric and about 250 psi above atmospheric pressure, at least about 900 liters per second of a substantially non-noxious and non-toxic combustion product.

64. A compact pyrotechnic inflator device comprising:

at least one layer of an ignition-enhancing material;

at least one thin layer of a gas-generating composition in physical contact with the ignition-enhancing layer, said gas-generating composition comprising:

about 10 to about 60 weight percent of glycidyl azide polymer,

about 40 to about 90 weight percent of oxidizer, and

about .5 to about 5 weight percent acrylate; and

means for initiating combustion of the gas-generation composition,

wherein the polymer, oxidizer and acrylate are combined in portions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 1000 psi above atmospheric pressure, a substantially non-noxious and non-toxic combustion product.

65. An inflator device comprising a gas-generating composition, said gas-generating composition comprising:

an azido polymer;
a curing agent; and
an oxidizer

wherein the polymer, the curing agent and the oxidizer are combined in proportions sufficient to generate, upon combustion of the composition at a pressure between about atmospheric pressure and about 1000 psi above atmospheric pressure, substantially non-noxious and non-toxic gas combustion product at a pressurization rate between about 5 and about 24 kPa per second when deployed at about 21° C.

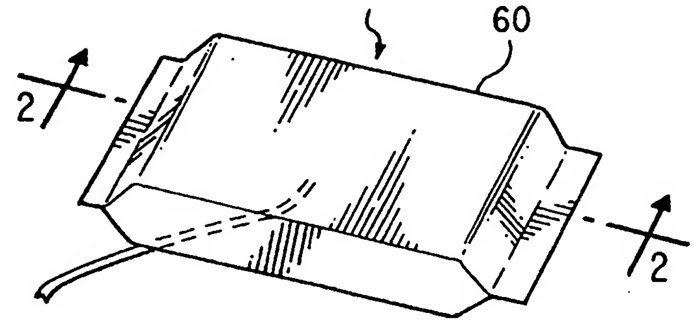

FIG. 1

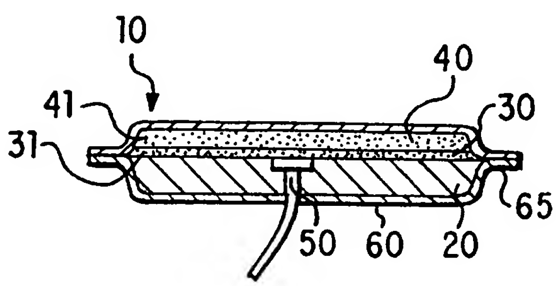

FIG. 2

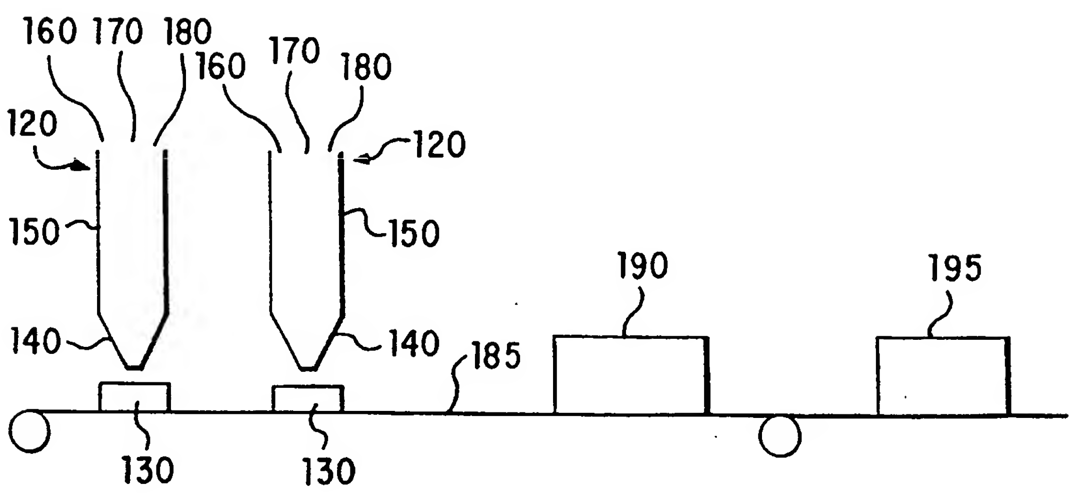

FIG. 4

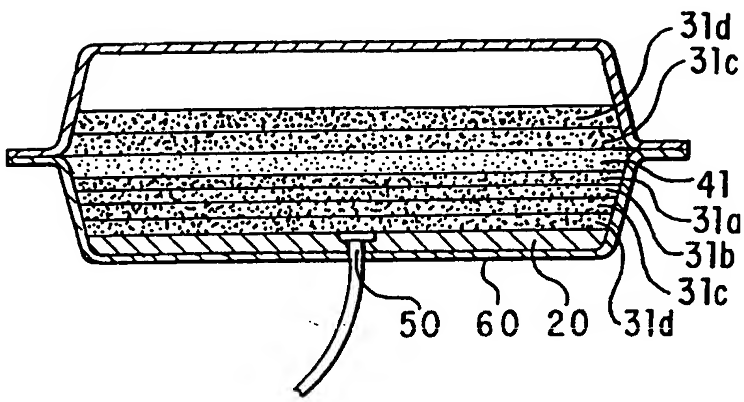

FIG. 2A

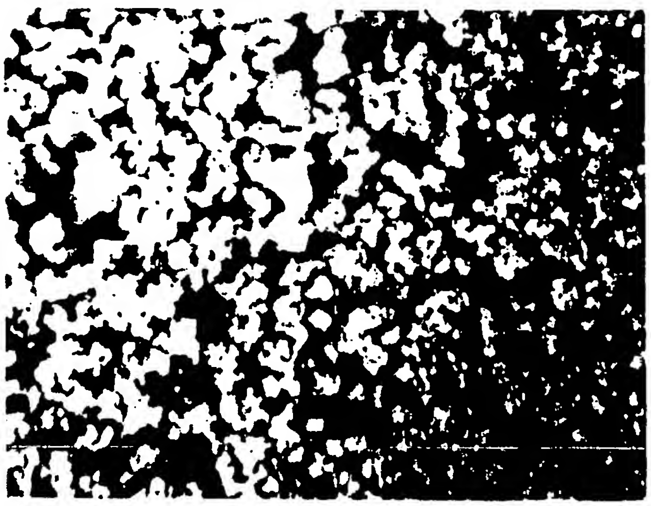

FIG.3

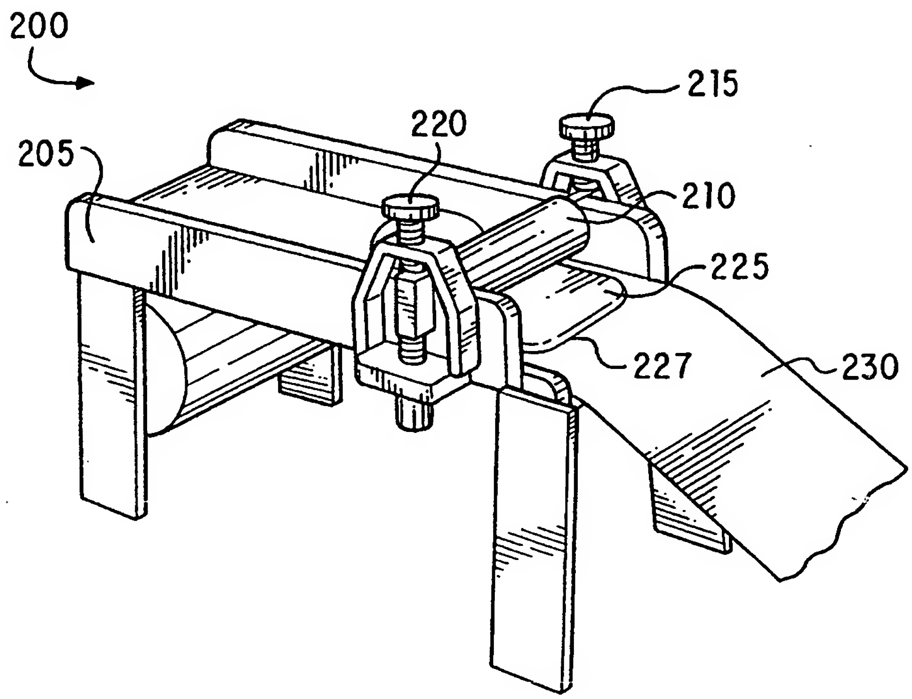

FIG. 4A

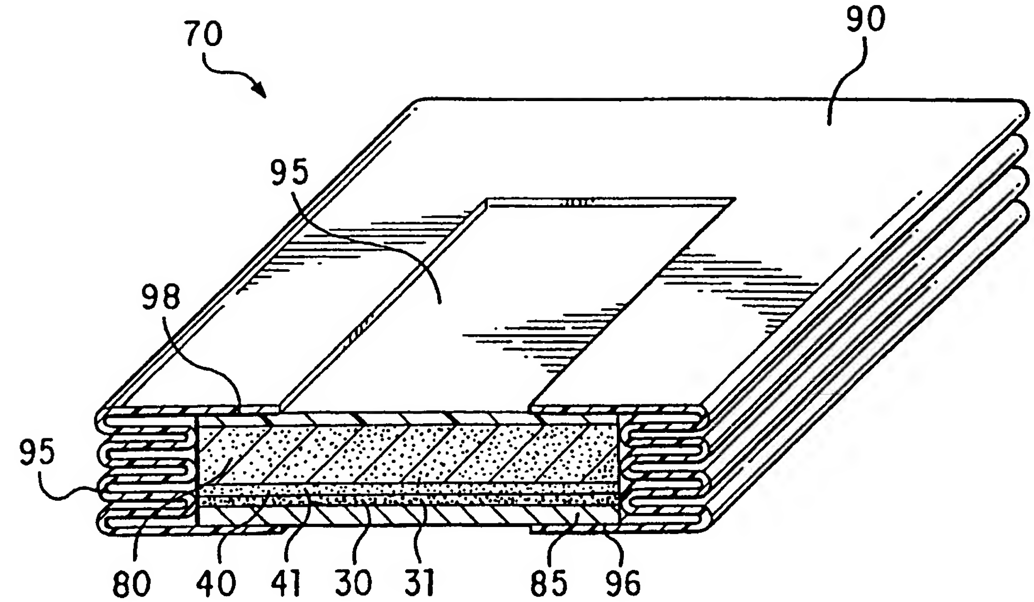

FIG. 5

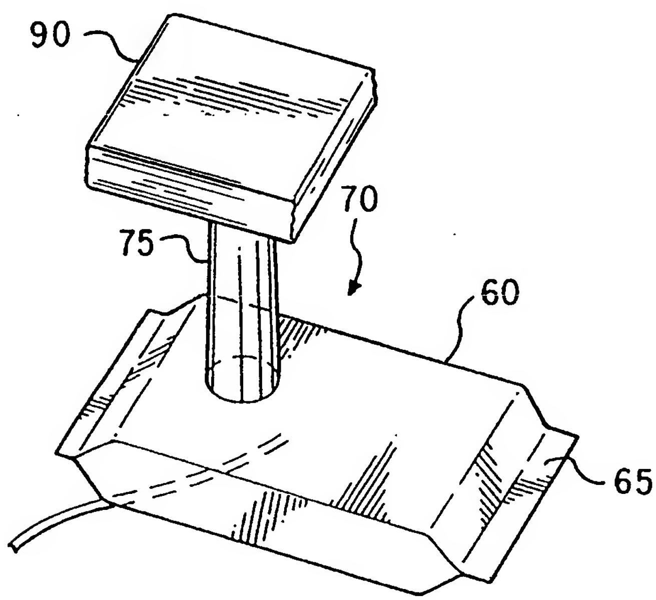

FIG. 6

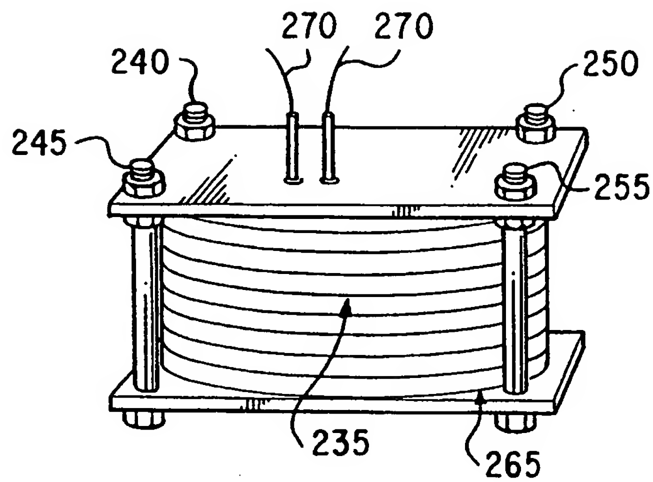
270
270
240
250
245
255
235
265

FIG. 7

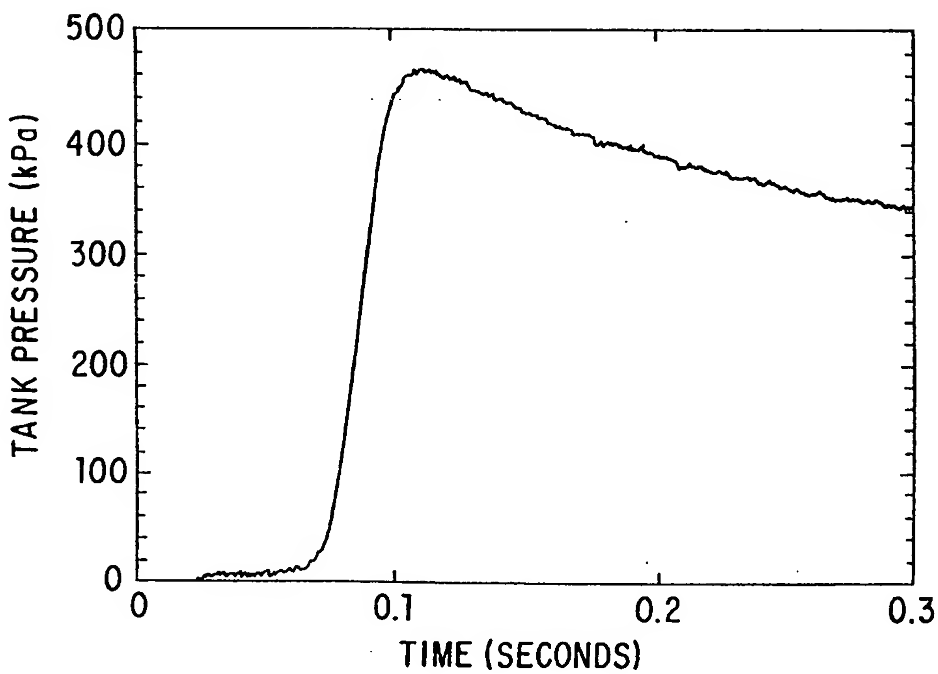
500
400
300
200
100
0
TANK PRESSURE (kPa)
0
0.1
0.2
0.3
TIME (SECONDS)

FIG. 8

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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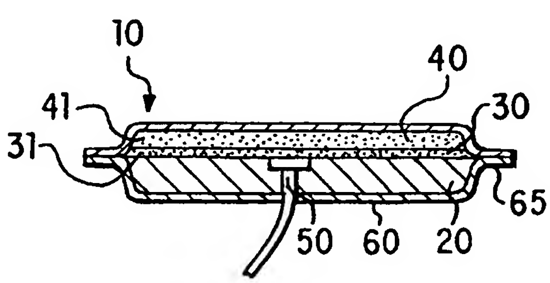
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: THIN INFLATOR AND AZIDE POLYMER COMPOSITION THEREOF



(57) Abstract: A compact, i.e., very thin inflator device (10) includes a gas generating composition. The gas generating composition comprises an azido polymer, a curing agent and an oxidizer. These ingredients are combined in proportions sufficient to generate, upon combustion at a pressure between about atmospheric and 1000 psi above atmospheric pressure, preferably 250 psi above atmospheric pressure, at least 900 liters per second of a substantially non-noxious and non-toxic gaseous combustion product. Gas generating composition (40, 41), optionally supported upon substrate (20) may be in contact with layer (30, 31) of ignition-enhancing material, which is adapted to transmit heat to gas generating composition (40, 41) from ignition means (50).

WO 99/38725 A3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/02169

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B60R 21/28; C06B 45/10
US CL : 280/741; 149/19.6, 15

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 280/741; 149/19.6, 15

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST: thin layer, class 280 in subclasses 730-749, class 149, filter, ceramic, foam.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,925,909 A (KUBOTA et al.) 15 May 1990 (15.05.1990), col. 7, "Table 2", Example 2.	1-2, 6, 8, 10-12
X --- Y	US 5,589,661 A (MENKE et al.) 31 December 1996 (31.12.1996), col. 1, lines 5-8, col. 4, lines 25-45.	1-2, 6-13, 34, 65 ----------- 1-65
Y	US 5,681,904 A (MANZARA) 28 October 1997 (28.10.1997), col. 3, lines 33-38, col. 5, lines 31-40, col. 9, lines 1-35.	3-5, 38, 62
X --- Y	US 5,507,891 A (ZEIGLER) 16 April 1996 (16.04.1996), The Abstract, col. 4, lines 1-12, col. 3, lines 1-11.	1-2, 6, 8, 10-13, 17, 34-36, 65 ----------- 1-65
Y	US 5,565,650 A (JOHANNESSEN et al.) 15 October 1996 (15.10.1996) col. 1, lines 1-8, col. 3, lines 18-26, col. 6, lines 54-58.	1-65
Y	US 5,536,339 A (VERNEKER) 16 July 1996 (16.07.1996), col. 2, lines 40-51.	1-65
Y	US 5,273,313 A (KLOBER et al.) 28 December 1993 (28.12.1993), the Abstract, Fig 1-2, col. 2, line 58- col. 3, line 14.	1-65

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 16 July 2001 (16.07.2001)	Date of mailing of the international search report 02 AUG 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Edward A. Miller Telephone No. (703) 308-1113

INTERNATIONAL SEARCH REPORT	International application No. PCT/US99/02169

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,066,039 A (SHITANOKI et al.) 19 November 1991, (19.11.1991), the Abstract, Fig 1-2, col. 3, lines 33-45.	13-15, 17, 35-37, 40-45
A	US 5,551,725 A (LUDWIG) 03 September 1996 (03.09.1996).	1
Y	US 5,090,322 A (ALLFORD) 25 February 1992 (25.02.1992), The Abstract, Fig 2.	20-22, 25-32, 49-51, 55-58
Y	UA 5,606,146 A (DANEN et al.) 25 February 1997 (25.02.1997), the Abstract, col. 1, lines 14-20, col. 5, lines 1-35, Fig. 1	20-22, 25-32, 49-51, 55-58
Y	US 3,311,459 A (FRANCIS et al.) 28 March 1967 (29.03.1967), col. 1, lines 8-70.	1-65
Y	US 5,505,799 A (MAKOWIECKI) 09 April 1996 (09.04.1996), the Abstract, col. 1, lines 48-55.	1-65
Y	US 5,024,160 A (CANTERBERRY et al.) 18 June 1991 (18.06.1991), the Abstract, Fig. 4.	16, 53
Y	US 3,744,427 A (GOOD et al.) 10 July 1973 (10.07.1973), the Abstract.	16, 53
Y	US 4,681,643 A (COLGATE et al.) 21 July 1987 (21.07.1987), the Abstract, col. 7, lines 1-24.	16, 53
Y	US 3,322,515 A (DITTRICH et al.) 30 May 1967 (30.05.1967), col. 3, lie 57-col. 4, line 4.	29-32, 50, 55-57.
Y	US 5,360,232 A (LOWE et al.) 01 November 1994 (01.11.1994), col. 8, lines 33-68.	25-28, 46-47, 59-60
Y	US 5,582,427 A (RINK et al.) 10 December 1996 (10.12.1996), col. 3, lines 48-67.	25-28, 46-47, 59-60
Y	US 4,878,690 A (CUNNINGHAM) 07 November 1989 (07.11.1989), col. 5, lines 3-41.	25-28, 46-47, 59-60

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/02169

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
Please See Continuation Sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.: 1-65, upon consideration of the protest.
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☒ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-12, drawn to a composition.

Group II, claim(s) 13-65, drawn to a device.

The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: The corresponding special technical feature must be special, novel and inventive. The feature of an azide polymer in a gas generator is neither novel nor inventive.

This application contains claims directed to more than one species of the generic invention. These species are deemed to lack unity of invention because they are not so linked as to form a single general inventive concept under PCT Rule 13.1.

In order for more than one species to be examined, the appropriate additional examination fees must be paid. The species are as follows:

As to compositions:
A. Species with or without an acrylate cure, such as claims 3-5, 38 and 62, and
B. Species with or without inorganic salt oxidizer, such as claim 6.

As to devices:
C. Devices with or without thin propellant layer, such as claims 14-16, 51-52 and 64,
D. Species with or without a substrate, such as claims 17, 19, 37 and 54,
E. Species with or without ignition means, such as claims 35-36, 40-41 and 64,
F. Species with or without housing means, such as claims 42 and 51,
G. Species with or without inflatable envelope means, such as claims 45 and 61,
H. Species with or without filtration means, such as claims 42 and 51,
I. Species with or without ignition enhancer means, such as claims 18, 37 and 64,
J. Species with or without metal foil enhancer means, such as claims 20-24, 49 and 58,
K. Species with or without multilayer enhancer means, such as claims 29-33, 50 and 55-57.

The claims are deemed to correspond to the species listed above in the above manner.

The following claim(s) are generic: No claims are generic to all of the species. Instead, various members of the species are combined in various different combinations.

The species listed above do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, the species lack the same or corresponding special technical features for the following reasons: The broad concepts of an azide polymer binder with oxidizer, as well as a thin layer air bag device, are well known, e.g., not novel or inventive, and thus these do not for a proper special technical feature. Further, the respective categories of species are found in various combinations and permutations, whereby the presence or absence of a single species does not form a common special technical feature. Also, a subcombination of a device with an azide polymer/oxidizer gas generating composition does not form a proper genus for multiple combinations containing the same subcombination.